Pumping Test Guidelines for Horizons Regional Council

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Limitations:

The report has been prepared for Horizons Regional Council, according to their instructions, for the particular objectives described in the report. The information contained in the report should not be used by anyone else or for any other purposes.

Executive Summary

Pumping tests are one of the most important tools for understanding the performance of an abstraction well and the effects that its use will have on the surrounding groundwater conditions. It therefore provides important information for the well owner and for Horizons Regional Council, who is the authority that grants consents for the abstraction and use of groundwater. However, if tests are not undertaken and interpreted in the correct manner, they can provide misleading information which can lead to a well being used in a way that is beyond the limits of its performance and/or result in incorrect decisions being reached regarding its effects on the environment.

The purpose of these guidelines is to provide groundwater users with some clear guidance about how to carry out pumping tests and some preliminary guidance on how to analyse them. Many textbooks and technical papers have been written on this topic. The purpose of these guidelines is to provide a simplified document that briefly outlines the critical factors for a successful pumping test. These factors are:

- understanding the groundwater setting in which the test is occurring;
- a pumping rate and test duration that is sufficient to provide useful measurements at the observation points;
- careful control of both the pumping rate and the discharge of the pumped water, so that it does not interfere with the test measurements;
- an appropriate monitoring regime that will provide the information that is required in relation to:
  - accurate measurements of the discharge rate;
  - location and design of observation wells;
  - accurate measurements of water levels both before, during and after the test that allow the effects of the pumping test to be identified;
  - measurements of relevant surface flow features;
- appropriate processing of the test data to correctly separate out the effects of the pumping test from other influences that may have occurred during the test;
- accurate interpretation of the test data to correctly define parameters related to well performance and aquifer characteristics;
- reporting of the test results in a manner that clearly defines the purpose of the test, the measurements that have been made, the interpretation of the data and its application to achieve the purpose of the test. In particular, the report must be sufficiently detailed and transparent so that all the relevant conclusions can be verified by an independent peer review.

To achieve the components of a successful pumping test requires careful planning. Well owners and their advisers should involve Horizons staff in this pre-test planning process to ensure that all regulatory requirements are met and to receive the benefit of their specialist knowledge of groundwater conditions and issues within the test area.

The application of these guidelines, coupled with the combined input of well owners, drillers, professional advisers and Horizons staff will contribute to the improved knowledge and management of groundwater within the Horizons region.

Disclaimer

This document has been prepared to provide guidance to groundwater users and consent applicants within the Horizons region. It does not prescribe any absolute requirements and the final determination for the implementation of any pumping test must be made by an appropriately qualified professional. Horizons and Pattle Delamore Partners Ltd takes no responsibility for the outcome of any pumping tests or any consequential outcome that relies in whole or in part on a pumping test.

Persons or organisations undertaking pumping tests within the Horizons region should fully inform themselves as to permit and consent requirements for undertaking such tests and must plan and take full responsibility for health and safety issues related to undertaking such tests.

This document has been prepared for the sole purpose of providing general guidance to people who carry out pumping tests within the Horizons region. It should not be used for any other purposes.

Acknowledgement

This guideline document has been prepared by Pattle Delamore Partners Ltd based on an earlier draft document prepared by Mr Wayne Russell, Dr Mark Gyopari and Mr Scott Wilson, which was reviewed by Mr Paul White.

The preparation of this current document has been overseen by Hisham Zarour (former Horizons Environmental Scientist – Groundwater) and Abby Matthews (current Horizons Environmental Scientist – Groundwater).

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1.0 Introduction

A pumping test is typically carried out for two main reasons. Firstly, the test can provide information on the yield and drawdown characteristics of a production well. This information is important for selecting the correct pump and operating regime for the well and it can also provide a measure of how efficient the well is at removing water from the aquifer (e.g. how much drawdown in the water level occurs for any particular abstraction rate). Secondly, the test can provide information on the effects that a groundwater abstraction will have on the surrounding water resource and can be used to define parameters that describe the movement of water through the ground e.g. the transmissivity and storativity of an aquifer and the leakage through aquitards. The definition of these parameters can be used to make longer term predictions of the environmental effects that could arise from the long-term abstraction of groundwater from the tested well.

Therefore, pumping tests provide an important source of information for well owners and for Horizons Regional Council, who must make decisions on applications for resource consents to abstract and use groundwater. However, there are a wide range of ways in which a pumping test can be undertaken. The correct design of a test must be based on the purpose for which it is being undertaken and the hydrogeologic setting in which it occurs.

The primary objective of this document is to provide:

A set of practical guidelines that will hep produce high quality pumping test data.

In particular, Horizons wants to ensure that pumping tests conducted on its region are:

- focussed on providing relevant information to address resource management issues;
- designed to account for the site specific hydrogeologic setting;
- carefully planned and implemented;
- of appropriate duration;
- carried out efficiently and cost effectively;
- correctly interpreted, taking into account both the hydrogeologic setting and the resource management issues that apply to that setting;
- clearly reported so that results can be readily audited.

1.1 Supporting Documents

Some pumping test guidelines have already been prepared for use in other regions in New Zealand, including:

- Environment Canterbury;
- Hawkes Bay Regional Council.

It is important to recognise that these guideline documents (including this current document) do not provide the most thorough and complete documentation of all pumping test procedures. Rather they provide an overview guideline of some key considerations that must be taken into account when planning and implementing pumping tests.

Other documents that provide more comprehensive background information on undertaking and analysing pumping tests include:

- Driscoll, F.G. (ed) 1986; Groundwater and Wells US filter/Johnson screens St Paul;
- Kruseman, G.P. and de Ridder, N.A. 1994: Analysis and Evaluation of Pumping Test Data (2nd Edition, Completely Revised) Publication 47. International Institute for Land Reclamation and Improvement, Wageningen, The Netherlands. This is available online through http://www.alterra.wur.nl/UK/publications/ILRI-publications/Downloadable

Many other publications, including original papers, are available on the topic of pump test practice. Additional reference material is available at http://en.wikipedia.org/wiki/Aquifer_test.

2.0 Horizons Requirements

These guidelines have been prepared specifically for Horizons Regional Council. Therefore, this section of the guidelines provides a brief overview of the groundwater conditions that exist in the region and the water resource management issues which may be aided by pumping test information.

2.1 Hydrogeology of the Manawatu-Wanganui Region

An aquifer is an underground layer of water-bearing, permeable material (rock or sediment) from which useful volumes of groundwater can be economically extracted.

In the Manawatu-Wanganui region, aquifers have developed as a result of alluvial processes (mainly gravels), marine processes (mainly sands), dune building (fine sands) or fracturing of consolidated rocks (greywacke).

The geological processes which formed the aquifers have determined the type and behaviour of these aquifers. For example:

- alluvial deposits, being typically river deposits (channels or terraces), tend to comprise lenses of gravels, with varying degrees of connection with other lenses i.e. possibly limited in width but with some extension along the direction of the channel;
- marine deposits (beach deposits and marine terraces) generally tend to be more laterally extensive;
- dune sand deposits tend to be finer grained, resulting in lower permeabilities and may be limited in extent;
- fractured rock aquifers have been formed by faulting and folding of consolidated rocks.

Each aquifer type may have been disrupted, to a degree, by faulting and folding.

Depending on the sequence of deposition, aquifers may be:

- confined;
- semi-confined;
- unconfined.

Semi-confined aquifers are often referred to as “leaky” aquifers.

Confined aquifers are generally (but not always) encountered where gravels, sands or sandstones have been overlain by muds, silts, clays, peats, siltstones or mudstones. Confined aquifers may give rise to artesian wells which can flow naturally at the ground surface. Such wells occur across the Horizons region and require special consideration when planning pumping tests. Water stored within confined aquifers is released into an abstraction well due to a change in pressure within the aquifer, but there is no actual dewatering of the pore space.

Unconfined aquifers are typically shallow. They are replenished directly from rainfall infiltration into the ground surface or from water flowing from streams, lakes and ponds, or wetlands. These aquifers may discharge to streams, ponds, lakes or wetlands. Water stored in an unconfined aquifer is released from the aquifer to an abstraction well by the physical dewatering of the pore space at the water table.

Leaky aquifers are common across the region and in many areas it is appropriate to consider an aquifer as likely to be leaky until proven otherwise. Pumping from leaky aquifers has the potential to affect shallower wells and also surface water bodies (wetlands, streams and ponds), because leaky aquifers can take recharge from shallower (or deeper) strata. They may initially respond to pumping in a similar manner to a confined aquifer, but leakage of water through the low permeability confining layer allows drawdown effects to be transmitted to other water bearing layers.

2.2 Overview of Groundwater Issues

Groundwater use is increasing in the region. The demands for pasture irrigation, town supply and industrial use are increasing, therefore it is becoming more important over time to understand the effects of each new groundwater take on existing users, on the groundwater resource, and on the environment, particularly on surface water bodies (streams, lakes and wetlands), which may be connected to the groundwater systems. It is also important to understand whether there is any risk of sea-water intrusion as a result of groundwater pumping in coastal areas.

The natural variability of the geology and groundwater conditions in the Horizons region means that site specific data on well construction, well performance and aquifer behaviour are needed to understand the effects of groundwater abstractions.

These guidelines aim to help with the collection of good quality pump test data for the purposes of:

- quantifying drawdown interference effect on existing well users;
- determining the effects that groundwater abstraction may have on surface water flows;
- assessing the effects on shallower groundwater, and surface water bodies, including wetlands and lakes;
- demonstrating the yield, efficiency and sustainability of a well;
- providing aquifer parameters for modelling groundwater flow, pumping effects and contaminant movement.

2.3 Regulatory Requirements

The management of water resources in the Horizons region is currently set out in the Land and Water Regional Plan. This will eventually be superseded by the Proposed One Plan (POP) which has been publicly notified and at the time of preparing these guidelines is going through the process of hearing submissions. Until all submissions on the groundwater aspects of the POP are resolved, then consideration must be given to both these planning documents. On the basis that the POP indicates the likely future requirements, the following points summarise the key regulatory requirements for pumping tests:

- well drilling – the drilling, construction or alteration of any well that extends into groundwater is a "restricted discretionary activity" that requires a resource consent from Horizons. Construction of wells should comply with NZS 4411:2001 Environmental Standard for Drilling of Soil and Rock and information on the well must be provided to Horizons;
- pumping tests on wells and the associated discharge of the pumped water is a "permitted activity", which does not require a resource consent, provided it meets the following conditions:

  a) the Regional Council shall be notified in writing at least five working days prior to commencement of the test;

  b) the rate of take shall not exceed 60 L/s;

  c) the duration of any single test shall not exceed seven days;

  d) the activity shall be carried out in accordance with the NZS 4411:2001 Environmental Standard for Drilling of Soil and Rock;

  e) the take must not be from any rare, threatened or at-risk habitat;

  f) the take shall not lower the water level in any wetland that is a rare or threatened habitat;

  g) where the discharge is into water the discharge shall not:

     (i) change the receiving water temperature by more than 3ºC after reasonable mixing;

     (ii) cause erosion of the bed of the receiving waterbody;

     (iii) alter the natural course of the receiving waterbody;

     (iv) cause visibly noticeable iron flocculation in the receiving waterbody;

  h) where the discharge is onto land the discharge shall not increase land instability or the risk of erosion;

  i) the discharge shall not cause or contribute to flooding on any other property;

  j) following completion of the test the well shall be covered and secured as soon as practicable;

  k) records of all pumping and recovery tests shall be kept by the owner, including the location of the pumped well and any observation wells, the flow rate during pumping, the water level at the pumped well and any observation wells, and the time at which all measurements were taken. The records shall be forwarded to the Regional Council within one month of completion of the tests.

If these conditions cannot be complied with, then a resource consent application will need to be lodged with Horizons to allow the test to occur.

In all cases it is recommended that consultation is carried out with Horizons staff at an early stage of planning for a pumping test to ensure that all regulatory requirements are met.

3.0 Introduction to Pumping Tests

A pumping test involves pumping a well at a measured rate for a fixed period of time and measuring the change in groundwater levels (and in some situations also a surface waterway) in response to that pumping. Those measured responses are then matched to theoretical responses from idealised aquifers to provide an approximate characterisation of the tested well and the groundwater system from which it draws its water. Therefore it is important for the test to be carried out in a manner that is consistent with the subsequent analysis that will be applied to the test data.

3.1 Planning the Pumping Test

Careful planning of a pumping test is important to achieve a successful outcome. This planning must include the following:

- a review of the drillers well log to consider where the pump will be placed, the drawdown that is available within the pumped well and the pumping rate that can be used;
- the drillers description of the strata at the pumped well and similar descriptions from nearby wells to consider the nature of the strata in the area, its degree of variability and the type of aquifer that is to be tested;
- a consideration of nearby wells and surface waterways to identify which hydrogeologic characteristics might be affected by the test and what monitoring should be undertaken during the test;
- a consideration of the water quality in the area and in the pumped well and whether that may alter as a result of the pumping test. This may include a need to implement disinfection measures for pump testing equipment to avoid the risk of transferring iron bacteria;
- a consideration of any issues related to land settlement and the discharge of the test water that may need special measures to avoid adverse effects during the testing programme;
- careful planning of the timing and duration of the test to provide the best opportunity to identify the effects from the test relative to background trends;
- consideration of disposal or storage requirements for water abstracted during the pumping test.

With regard to the timing of the test, it should ideally be carried out during a period of settled weather conditions. In particular, heavy rainfall events or times of large barometric fluctuations (for confined aquifers) should be avoided. The objective of the test is to measure the change in water levels caused by the pumping test. For that reason, it is important to conduct the test at a time when other pumping wells are not in use.

The initial pump test planning should be undertaken by the well owner, the well driller and an advisor with appropriate expertise in well design and groundwater science. It is strongly recommended that consultation with Horizons staff be undertaken to review the initial pump test plan.

Based on this consultative approach, it is recommended that a "Pump Test Plan" is prepared to document the following details:

- the purpose of the test;
- the hydrogeologic setting;
- details of the pumped well and any observation wells that will be used;
- a clear description of how the test will be carried out, including all the details of monitoring that will be undertaken. This detailed outline of the test should include a description of all the relevant components described in Sections 4 and 5 of these guidelines;
- confirmation of compliance with regulatory requirements;
- a description of any disinfection requirements;
- a health and safety plan to ensure compliance with the Health and Safety in Employment Act 1992.

The level of detail in this Pump Test Plan should be appropriate for the scale of the test. It would be prudent to have the plan reviewed by Horizons staff prior to the arrangements for the test commencing.

4.0 Components of a Pumping Test

The following components will be involved in the pumping test.

4.1 The Pumped Well

The pumped well is used to abstract groundwater so that the response to that abstraction can be measured. It is important to know the depth of the screened section from which water is abstracted and the drillers description of the strata both from the pumped well and how that description compares with neighbouring wells. This evaluation of the drillers logs allows the zone from which water is withdrawn to be defined. Ideally the pumped well is screened across a single discrete water bearing unit.

The pumping rate shall be determined by the well diameter (which limits the size of the pump within the well) and the available drawdown (which is limited by the depth at which the pump is set). It is important that the test does not draw the water level down into the screened section of the pumping well.

It is generally desirable for the pumping rate to be at least as high as the maximum pumping rate that will be used for the well. Furthermore, if the test is being undertaken to measure a drawdown response in neighbouring wells or waterways then the highest possible pumping rate will generate the biggest response. However, it is important not to over pump the well beyond the rate for which it has been developed or to cause too much drawdown in the pumped well, which could cause the need for an unplanned adjustment to the pumping rate part of the way through a pumping test.

It is important that the pump is fitted with a foot valve to prevent the discharge of water back into the well once pumping stops.

Local disturbances caused by the pumping test (e.g. due to the discharge of water, Section 4.2, or generator noise) should be taken into account when planning the pumping test.

It is very desirable to carry out a brief trial pumping period the day before the test to ensure all equipment works and to establish the correct gate valve setting for the desired pumping rate.

Therefore, key aspects to consider regarding the pumping well are:

- details of the screened depth;
- confirm the strata and that the screen occurs across a single aquifer;
- the static water level and how this might vary throughout the test;
- the ability to measure the water level in the pumped well across the full range of fluctuations that will occur prior to, during and following the test;
- details of the depth of the pump and the maximum drawdown that is available within the well;

- confirm the pumping rate based on the drillers information about well development and the available drawdown above the pump;
- confirm that the pump has a foot valve.

4.2 Discharge of the Pumped Water

Careful consideration must be given to the discharge of the pumped water. It is important that the pumped water must not infiltrate into areas where it can affect the measurements of groundwater levels and surface waterways that are being made as part of the monitoring programme for the test. To avoid this problem, water may need to be piped a long way from the test site and/or into an existing flowing waterway, downstream of any surface water measurements. The discharge must not adversely impact on the receiving environment, either due to the creation of flooding problems, erosion of the stream bed or stream banks or an adverse change in water quality (e.g. due to hot or saline groundwater).

4.3 Observation Wells

Observation wells are utilised to measure the change in water levels caused by the abstraction of water from the pumped well. As with the pumped well, it is important to have information on the position of the screened section of the observation well and a description of the strata in the vicinity of the observation wells. They should be screened across a single aquifer and at least one observation well should be screened across the same aquifer as the pumping well. The lateral separation distance between the pumped well and an observation well in the pumped aquifer should be sufficient to avoid vertical flow effects (i.e. typically at least 20 m away), but close enough to record a measurable drawdown response. Consideration should also be given to monitoring water levels in an observation well that is screened within the monitored aquifer(s) but is unaffected by the pumping test. This can provide a useful control to check on the background level fluctuations that occur throughout the period of the pumping test.

The location of the pumped well and all the observation wells must be carefully plotted on a site location map and the separation distance between them must be accurately measured.

It is very desirable for observation wells to be unused during the pumping test and to be located in an area where any changes caused by the pumping test will be clearly distinguishable from any other drawdown interference that may occur in this area. If an observation well must be used for abstraction purposes during a test, then that abstraction must be carefully controlled and limited to times that will still allow the drawdown effects from the pumping well to be clearly identified.

If observation wells are privately owned, it is important to keep the owners informed of all the monitoring activities that are being carried out throughout the test.

It is desirable to have more than one observation well within the pumped aquifer at different distances and directions from the pumped well. These multiple measurement points will provide an indication of the variability in aquifer characteristics.

Key information for each observation well is:

- its exact location, to determine the distance and direction from the pumped well;
- the screened depth and its position within the sequence of strata relative to the pumped well;
- the ability to measure the full range of water levels that will occur during the test;
- the elevation of the water level monitoring point in terms of distance with respect to ground level and perhaps also with respect to a common datum between all observation wells (this datum could be mean sea level);
- the well should not be in use, or if this is not possible, its use must be carefully controlled during the test.

A record sheet to describe the details of each well used during the pumping test is presented on the following page.

4.4 Nearby Surface Waterways

Where it is considered that a pumping test may create a response in a surface waterway, then consideration should be given to monitoring that surface waterway during the test. These should be measurements of water level (in a wetland or pond) or flow (in a stream or drain). However, careful consideration should be given to the accuracy of those measurements as they may not be sufficiently sensitive to detect the scale of response that could be created by the pumping test.

4.5 Sterilisation and Disinfection of Equipment

Bacteria can grow in a groundwater environment (iron bacteria included) and can be transferred from well to well by the pump test equipment. Equipment placed in neighbouring water supply wells that are being monitored as part of the test may need to be sterilised to ensure no bacterial transference occurs.

Similarly, test pumps, rising mains and power cables used temporarily in a well may need to be sterilised before insertion.

Horizons advise that a solution of 100 mg/L of available chlorine can be used to sterilise equipment. Chlorine is readily available as calcium hypochlorite (for swimming pool treatment). Such material usually contains approximately 70% of available chlorine. Hence, for this type of material, a ratio of 14.3 grams of calcium hypochlorite would be mixed with 100 L of water to provide the required strength solution.

A disinfection plan should be included in the pumping test plan to ensure no transference of bacteria can occur.

Record of Well Used for Pumping Test

Well Number: ____

Well Owner: _______________________ Contact Phone No.: ________________

Drilling Firm: ______________________ Date Drilled: ______________________

Diameter (mm): ____

Drilled Depth (m): ____

Screen Depth (m below ground level): ______ Top: _______ Bottom: ______

Type of Screen: ____

____

Well Use: ____

Purpose for Inclusion in Pumping Test: _____________________________________

Description of Measuring Point: ____

(include photo of well head identifying the measuring point)

Location Map of Well:

Additional Comments: ____

____

____

Attach drillers well log.

Information Recorded by: ____

Date: ____

5.0 Pump Test Measurements

A number of measurements are made during the pumping test which are later used in the analysis to determine how the pumped well and its associated groundwater system respond to the stress caused by the pumping. All measurements must be accurately made and carefully stored and documented so that they are available for future reference.

5.1 Discharge Rate

Careful measurement and control of the discharge rate is required throughout the test. For most tests, the rate must be kept constant for prolonged periods. Although as the water level in the pumped well alters during the test, it is not uncommon for the discharge rate to also alter. Therefore, fine adjustment can often be required throughout the test to maintain a constant rate. These can best be achieved by careful adjustment to a gate valve positioned at the well head.

Whether or not such adjustments are needed depends on the accurate measurement and monitoring of the discharge rate throughout the test. These measurements are most accurately made with an orifice flow meter that has been calibrated in a laboratory flume. Orifice meters must be set up to lie horizontally, to have a free discharge of water out the end of the meter.

As an alternative to the orifice meter, an in-line flow meter can be used to measure the flow, although these too should be calibrated to ensure they provide an accurate measurement.

For very low rate pumping tests, simpler methods can be used, such as the time taken to fill a known volume (e.g. a bucket or tank). It is always important to maintain the discharge pipe at the same elevation throughout the test, including the times of flow measurement, to ensure that a constant rate is maintained.

Any alterations to the pumping rate that occur during the test must be accurately monitored. If the pump stops, the exact period of the stoppage must be identified and the water level monitoring frequency increased so that the effect of the stoppage on water levels during the test can be assessed and corrections applied if necessary.

5.2 Water Level Measurements

Water level measurements are required both in the pumped well and in the observation wells. These are ideally provided by pressure transducers which provide regular electronically stored measurements of water levels. However, careful planning needs to be included in the use of transducers, including:

- selecting the range and accuracy of the transducer that is appropriate for water level fluctuations that will occur;
- setting the transducer at an appropriate depth in the well to match its operating range and the expected water level fluctuations;

- recording the depth at which the transducer is set, relative to the measuring point datum for the well;
- ensuring that there is a barometric pressure compensation available for the pressure transducer reading.

Regardless of whether or not transducers are used, it is still important to make manual depth to water readings in all wells, as an independent check on the accuracy of the transducers and to provide all the water level data if transducers are not used. Electrical depth to water meters should be used with a graduated electrical cable. The length of this cable should be checked with a steel tape measure from time to time to ensure that its accuracy has not been distorted by stretching of the cable.

The measuring point for all water level measurements should be clearly marked so that a consistent set of measurements are made throughout the test.

In all tests, it is important to regularly monitor water levels for at least one hour prior to the pumping test to establish any background trends that are present. In some situations, monitoring for 24 hours or 7 days before the test may be needed to pick up regular patterns of fluctuations that occur in the test area.

The measurement of the static water level immediately prior to turning the pump on is essential, as it provides the reference point from which all drawdown effects will be determined.

The frequency of manual measurements during the test will vary, as set out in the test monitoring programme. The timing should be focussed on ensuring that the rate of water level change is accurately recorded. Therefore, more frequent measurements are made at the start of the test when water levels are changing fastest with the measurements becoming less frequent as the test proceeds – although a regular time interval may still be required throughout the duration of the test if there is a regular background fluctuation that must be corrected (e.g. tidal loading of a confined aquifer). In contrast, transducers can be set to achieve regular frequent measurements throughout the monitoring period.

All measurements must be clearly and accurately recorded on the recording sheets. This includes the actual time that measurements are made, rather than the pre-determined timing schedule if these do not match. It is helpful to plot the water level measurements on a graph as the test proceeds to identify the trends that are occurring. This also allows any unusual measurements readings to be identified and re-checked whilst the test is in progress.

A schematic diagram of the layout of the pumped well is shown in Figure 1.

5.3 Barometric Pressure

Confined aquifers (and some semi-confined aquifers) will experience water level change due to changes in air pressure during the pumping test. To check on this background pattern and correct it if necessary, a record of barometric pressure should be available for the period of water level monitoring that is carried out for the test.

In addition, pressure transducers that are not connected to the atmosphere will need an atmospheric pressure correction applied to their record. This is normally achieved by having an additional transducer recording atmospheric pressure at the test site at the same time interval as those transducers that are recording water levels.

5.4 Surface Waterways

If it is anticipated that a surface waterway could be affected by the test, then surface water measurements should be included in the test. These will take the form of water level measurements and/or surface flow measurements (either by spot flow gaugings or monitoring of water levels over a calibrated weir). However, consideration must be given to the accuracy of these measurements relative to the magnitude of the effect that is likely to occur. In many instances, it might not be possible to measure the relatively small effect that might occur during a pumping test in the size of a larger surface water body.

5.5 Water Quality

In some situations, a pumping test might induce a change in water quality during the testing period. If this is the case, then water quality monitoring could be undertaken during the test period. This would most likely involve indicator parameters such as electrical conductivity and/or temperature (both of which can be incorporated in the automatic recording regime of some pressure transducers). Alternatively, samples of the discharge water can be collected at the start and end of the testing period for a more thorough analysis at a testing laboratory to check if any changes have occurred during the test.

To establish the suitability of groundwater use, Horizons recommend carrying out water quality testing for a range of parameters, including, chemical, physical and bacteriological indicators. Sampling is best carried out towards the end of the pumping test when conditions have stabilised.

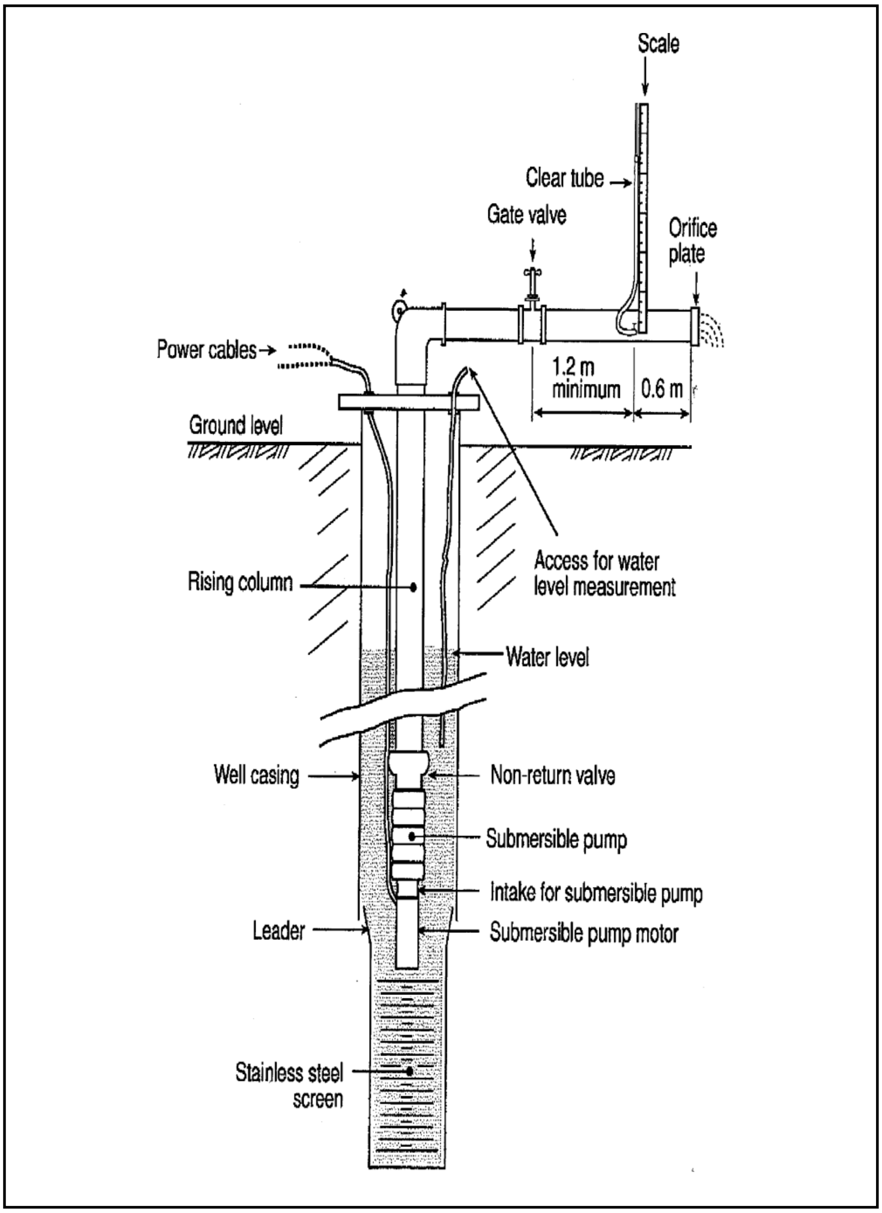

Figure 1: Pump and discharge example (from Canterbury Regional Council report R98-10).

6.0 Analysis of the Test Data

It is not the purpose of these guidelines to give a detailed description of pump test analysis methods. That is a subject that is covered by many text books. Furthermore, the analysis should only be undertaken by an appropriately qualified and experienced professional. However, there are three general steps to the processing of the data that are fundamental to the correct analysis of a pumping test. These are described below.

6.1 Collation of the Test Data

The first step in the analysis is to compile all the field data into a single database to show changes in all measurements relative to the start of the test – typically using a time scale in minutes.

Plots of all the time series at each observation point should be prepared for comparative purposes.

6.2 Identification of Effects Caused by the Test

The measurements made during the test will be a combination of the effects of the test combined with all the other background influences that were occurring during the monitoring period. A key part of a successful test analysis is the distillation of the changes caused by the pumping test from the raw measurements. This separation of the raw data involves determining the background trends and understanding the reasons for them.

This is best achieved by a careful evaluation of the time series record for each observation point and comparing measured trends before, during and after the pumping period. Comparison should also be made between different observation points to identify patterns at different locations relative to the pumping well.

The output from this exercise should be a dataset of effects caused solely by the pumping of the test well, which is then ready to be analysed. However, in some tests, there may need to be an iterative exercise undertaken between the test analysis and the quantification of the background trends until the most appropriate separation of these two effects is achieved.

6.3 Pumping Test Analysis

This measured change caused by pumping is then matched with theoretical calculated responses from idealised aquifers to determine the likely well performance characteristics, aquifer parameters and boundary conditions that affect the groundwater system that has been tested. This theoretical match should include both the drawdown and recovery components of the test.

Most test analyses assume the pumping well is of small diameter (with a limited storage volume) and fully penetrates the pumped aquifer. Where these assumptions are not met, special corrections to the analysis may be required.

The match between the theoretical model and the actual test data is presented by a graphical comparison of both the measured test data and the theoretical match. These can be shown through plots on a linear scale, a semi-log scale (log time versus drawdown or log distance versus drawdown) or on a log-log plot. All these different types of graphical scale should be used to emphasise different parts of the test.

It is very important to use consistent units for all terms defined in the analysis of the pumping test.

The output from the analysis is an equation and associated aquifer parameters that match the measured response to the pumping test. In many situations, the analysis of the test data does not provide a unique interpretation and several possible options must be trialled involving a range of potential groundwater models. A careful consideration and understanding of the groundwater setting will often provide the best guidance as to which analysis is the most appropriate interpretation for the measured data.

7.0 Reporting

The results of a pumping test and its analysis should be presented in a clearly set out report that presents the following information:

- an introductory comment;
- the purpose of the test;
- a description of the test location and the hydrogeologic setting. In particular, this should include a description of the pumped aquifer and any other aquitards or aquifer layers, based on information from drillers logs;
- details of the pumped well, the observation wells and any other monitoring points, including the drillers log for the wells;
- a description of how the test was carried out;
- a schedule of when each part of the test was carried out;
- a presentation of the raw test data;
- a description of any corrections that were made to the test data;
- a presentation of the corrected data and its conceptual interpretation;
- the numerical analysis of the pump test data and the results obtained from it;
- a discussion of the results of the test analysis and the implications for the long-term pumped well performance and the surrounding environment;
- a concluding comment;
- appendices to the report should include maps and diagrams of the test location and a presentation of the raw data, the corrected data and the data analysis.

All data from the pumping test and the processing of it should be stored in digital format and made available to Horizons staff and any other organisations for peer review and auditing purposes.

8.0 Pumping Test Plans

The approach to pumping tests that is set out in these guidelines can be refined into a specific plan, which can be prepared to aid in the completion of a successful pump test. The plan should be prepared in draft form and discussed with Horizons staff prior to finalising and implementing them.

A checklist that can be used to aid in the preparation of a plan is set out on the following pages:

Checklist for Planning Pumping Tests

Overview Planning

- ☐ Has the purpose of the test been clearly defined?
- ☐ Have the appropriate authorisations been obtained from Horizons?
- ☐ Is the hydrogeologic setting understood?
- ☐ Are the location of all the observation points, water discharge point and surface water locations accurately shown on a scale site plan and/or aerial photograph?
- ☐ Has a health and safety plan been prepared and have all personnel involved in the test been briefed regarding H&S issues?
- ☐ Has a disinfection programme been arranged if there is a risk of cross contamination?
- ☐ Has the pumping test been scheduled to occur during settled water level conditions?
- ☐ Has the test plan been presented to Horizons for discussion and review?

Pumped Well and Observation Well Details

- ☐ Has the appropriate permission been obtained from land owners to access wells?
- ☐ Will the noise and/or vibration from the pump and/or generator cause a neighbourhood disturbance and has that been discussed with those who may be affected?
- ☐ Is the drillers log for the pumped well and observation wells available?
- ☐ Are the screened intervals of the pumped well and observation wells known?
- ☐ Are the pumped well and observation wells screened within a single aquifer?
- ☐ Are the observation wells situated to record a good drawdown response and provide a background water level control?
- ☐ Are the pumped well and observation wells unused so as not to interfere with water level measurements?
- ☐ Can the abstraction rate be sustained for the full duration of the test?
- ☐ Can the pumping rate be controlled and adjusted with a gate valve?
- ☐ Has the maximum pumping rate been confirmed having regard to the pump size, the placement of the pump and the available drawdown?
- ☐ Does the pump have a foot valve?
- ☐ Has a pre-test pumping trial been undertaken?
- ☐ Have the arrangements for a suitable power supply for the duration of the pumping test been confirmed? (Including the re-fuelling requirements of a generator.)

Water Level Measurements

- ☐ Can water levels be measured across the full range of water level fluctuations?
- ☐ Have the depth to water tapes been checked to ensure reliable working order?
- ☐ Have all the water level measuring points been described and photographed?
- ☐ Has the placement of all pressure transducers been confirmed having regard to access and the range and accuracy of the transducer measurements?
- ☐ Will water level monitoring occur throughout all aspects of the pumping test?
  - prior to?
  - during?
  - following?
- ☐ Is barometric pressure being monitored throughout the monitoring record?
- ☐ Have arrangement been made to monitor:
  - surface water levels?
  - surface flow?
  - water quality?

Discharge

- ☐ Can the discharge rate be accurately measured? Which method will be used:
  - orifice meter?
  - in-line flow meter?
  - filling a known volume?
  - other ____________?
- ☐ Has the flow measuring equipment been calibrated?
- ☐ Will the water be discharged to avoid interference with the test measurements?
- ☐ Has the appropriate permission been obtained from Horizons and from land owners regarding the discharge of the water?
- ☐ Will the discharge avoid any adverse effects on its receiving environment, both physical and chemical?

Analysis of the Test Data

- ☐ Have all test measurements been collated into tidy hard copy records and an electronic database?
- ☐ Has a correction for background trends been applied to the data and described?
- ☐ Has a valid and consistent match been found for all the test data that is consistent with the conceptual hydrogeologic understanding of the area?
- ☐ Has a clear and concise report been prepared which can be used for an independent audit of the test and its findings?

Appendix 1

Step Drawdown Tests

Purpose: A step drawdown test is primarily undertaken to determine the yield and drawdown characteristics within the pumped well and the efficiency with which it produces water. It can be used to determine the long-term yield from a well and is often a useful test to carry out to determine the appropriate pumping rate to use for a longer term constant rate test.

Method: The production well should ideally be pumped at four different rates in sequence for a period of around 60 minutes for each pumping step. The analysis of the test is most straightforward if each pumping step is of the same duration. If it is intended to operate the well at a particular pumping rate (Q) then the four pumping steps would ideally be:

- 60% of Q;
- 80% of Q;
- Q;
- 120% of Q.

Water levels and discharge rates are measured in the pumping well prior to, during and following the pumping test. A monitoring sheet for the test is attached at the end of Appendix 1.

Water levels can also be made in nearby monitoring wells, although these measurements are not always essential to achieve the purpose of the step drawdown test. The reason for including nearby monitoring wells could be:

- to monitor background water level trends during the step drawdown test;
- to indicate which wells are affected by drawdown from the pumping well'
- to provide an indicative analysis of aquifer parameters (using similar methods to a constant rate test described in Appendix 2).

The first of these reasons for the adjacent monitoring well will help with the interpretation of the step drawdown test data. The latter two reasons are to gain more information from the test which is indicative of the information that is sought, in more detail, via a constant discharge test (Appendix 2).

Analysis: The test is typically analysed to match the field measurements to an equation that has the following form:

$$s_W = (a + b \log t)\ Q + CQ^2$$

Where: s_W is the drawdown in the pumping well;

t is the duration of the pumping time;

Q is the pumping rate.

The first term in the equation "(a + b log t) Q" defines the component of the drawdown caused by the linear flow of water through the aquifer.

The second term in the equation "CQ^2" defines the component of drawdown caused by turbulent flow of water as it enters the well casing and moves up to the pump.

A large component of turbulent flow indicates a well that is less efficient, although there are no absolute criteria for efficiency measurements. It is not unusual for turbulent head losses to make up 50% of the drawdown and whether or not a well should be considered inefficient is best judged by a comparison with similar wells in the same area.

A semi-log plot of the first step (long time versus drawdown) can be used to provide an estimate of aquifer transmissivity using Jacob's method.

A very good paper describing the analysis of step drawdown test data is "The Analysis and Planning of Step Drawdown Tests" by Lewis Clark, published in the Quarterly Journal of Engineering Geology (1977 Vol 10, pp 125-143).

Step Drawdown Test Record Sheet

Test Name:____________________ Pumping Well Number: _______________

Location: _____________________ Grid Reference: _____________________

Measuring Point Description and Datum: ___________________________________

Well Diameter (mm):____________ Screened Depth: ____________________

Type of Pump: ____

Depth of Pump Inlet:____________ Depth of Low Water Level Cutout (m):_________________

Ideal Measurement Time (minutes relative to start of test)	Actual Measurement Time			Depth to Water (in relative to measuring point)	Pumping Rate (L/s)	Person Measuring (initials)	Comment
	Date	Clock Time	Minutes Relative to Start of Test				
-60							Pre-test measurements
-45							
-30							
-15							
0							
1							Step 1
2							
3							
4							
5							
6							
7							
8							
10							
15							
20							
30							
40							
50							
60							
61							Step 2
62							

Ideal Measurement Time (minutes relative to start of test)	Actual Measurement Time			Depth to Water (in relative to measuring point)	Pumping Rate (L/s)	Person Measuring (initials)	Comment
	Date	Clock Time	Minutes Relative to Start of Test				
63							
64							
66							
68							
70							
75							
80							
90							
100							
110							
120							
121							Step 3
122							
123							
124							
126							
128							
130							
135							
140							
150							
160							
170							
180							
181							Step 4
182							
183							
184							
186							
188							
190							

Ideal Measurement Time (minutes relative to start of test)	Actual Measurement Time			Depth to Water (in relative to measuring point)	Pumping Rate (L/s)	Person Measuring (initials)	Comment
	Date	Clock Time	Minutes Relative to Start of Test				
195							
200							
210							
220							
230							
240							
241					0		Recovery
242					0		
243					0		
244					0		
246					0		
248					0		
250					0		
255					0		
260					0		
270					0		
280					0		
290					0		
300					0		

Appendix 2

Constant Rate Discharge Test

Purpose: The purpose of a constant rate discharge test is to define parameters that describe the movement of water through the groundwater system, to define the aquifer boundaries that affect that movement and to identify neighbouring wells and surface waterways that are affected by the use of the pumping well.

Method: The production well is pumped at the maximum rate that can be sustained at a constant value for the duration of the test. The length of the testing period is determined by the aquifer setting. A minimum duration of 24 hours is appropriate for a confined aquifer and 72 hours (3 days) for an unconfined aquifer. Longer durations are often required to assess aquifer boundary conditions (e.g. lateral low permeability boundaries, the transmission of drawdown effects upwards through a leaky aquitards and/or surface water depletion effects). However, the longer a test continues for, the more difficult it becomes to separate the drawdown effect of the pumping test relative to other background water level fluctuations that are occurring.

The location and screened depth of the monitoring wells should be chosen so as to achieve a good drawdown response over the duration of the test (with the exception of any monitoring well which has the purpose of providing background water level fluctuations).

Barometric pressure recording for longer tests in confined aquifers is important to allow a correction for water level changes caused by atmospheric pressure fluctuations.

Water levels and discharge rate measurements can be made at the intervals indicated on the attached recording sheets.

Depending on the environmental setting, a range of additional monitoring points can be included in the monitoring programme for the test, over and above the observation wells in the pumped aquiver. These include:

- monitoring wells in overlying shallower aquifers and/or aquitards that may be affected by leakage that occurs into the pumped aquifer;
- wetlands or areas of ponded water in the vicinity of the pumped well;
- flowing streams in the vicinity of the pumped well.

These features can all be monitored at a frequency similar to that used for the observation wells.

Analysis: There are a variety of analytical and numerical modelling solutions for constant rate tests. The main analytical methods are set out in the book Kruseman, G.P. and de Ridder, N.A.; 1994; Analysis and Evaluation of Pumping Test Data (2nd Edition, Completely Revised), Publication 47, International Institute for Land Reclamation and Improvement, Wageningen, The Netherlands (available online through http://www.alterra.wur.nl/UK/publications/ILRI-publications/downloadable).

It is very common for pumping test data not to have a unique solution, in that several different combinations of parameters may fit the data. Therefore, it is important to use a correct conceptual understanding of the hydrogeological setting to determine the best analysis of the test data.

The best analysis will provide an accurate match for all the measured deviations caused by the test, with a consistent range of aquifer parameters (allowing for natural variability) that is also consistent with the conceptual understanding of the aquifer behaviour. In many instances, a range of parameters will need to be reported to cover the possible matches to distinguish between which solution is most appropriate.

It is important that the analysis of the test data is undertaken in an open and transparent manner and that the potential uncertainties and variabilities in the output are clearly stated.

Constant Discharge Aquifer Test Pumped Well Record Sheet

Test Name:____________________ Pumping Well Number: _______________

Location: _____________________ Grid Reference: _____________________

Measuring Point Description and Datum: ___________________________________

Well Diameter (mm):____________ Screened Depth: ____________________

Type of Pump: ____

Depth of Pump Inlet:____________ Depth of Low Water Level Cutout (m):_________________

Ideal Measurement Time (minutes relative to start of test)	**Actual Measurement Time**			**Depth to Water (in relative to measuring point)**	**Pumping Rate (L/s)**	**Person Measuring (initials)**	**Comment**
	Date	**Clock Time**	**Minutes Relative to Start of Test**				
-60							Pre-test measurements
-45							
-30							
-15							
0							Start of pumping
0.5							
1.0							
1.5							
2							
3							
4							
5							
6							
7							
8							
9							
10							
12							
14							
16							
18							

Ideal Measurement Time (minutes relative to start of test)	Actual Measurement Time			Depth to Water (in relative to measuring point)	Pumping Rate (L/s)	Person Measuring (initials)	Comment
	Date	Clock Time	Minutes Relative to Start of Test				
20							
25							
30							
35							
40							
45							
50							
55							
60							
80							
100							
120							
150							
180							
210							
240							
300							
360							
420							
480							
540							
600							
660							
720							

* Measurements can continue at 3 hourly intervals through to the end of pumping, unless background fluctuations require more frequent intervals (e.g. hourly intervals where tidal loading occurs).

When the pump is turned off, the measurement schedule should repeat the schedule undertaken from the start of pumping.

Constant Discharge Aquifer Test Observation Well Record Sheet

Test Name:____________________ Pumping Well Number: _______________

Location: _____________________ Grid Reference: _____________________

Measuring Point Description and Datum: ___________________________________

Well Diameter (mm):____________ Screened Depth: ____________________

Type of Pump: ____

Depth of Pump Inlet:____________ Depth of Low Water Level Cutout (m):_________________

Ideal Measurement Time (minutes relative to start of test)	Actual Measurement Time			Depth to Water (in relative to measuring point)	Person Measuring (initials)	Comment
	Date	Clock Time	Minutes Relative to Start of Test			
-60						Pre-test measurements
-45						
-30						
-15						
0						Start of pumping
0.5						
1.0						
1.5						
2						
3						
4						
5						
6						
7						
8						
9						
10						
12						
14						
16						
18						

Ideal Measurement Time (minutes relative to start of test)	Actual Measurement Time			Depth to Water (in relative to measuring point)	Person Measuring (initials)	Comment
	Date	Clock Time	Minutes Relative to Start of Test			
20						
25						
30						
35						
40						
45						
50						
55						
60						
80						
100						
120						
150						
180						
210						
240						
300						
360						
420						
480						
540						
600						
660						
720						

Appendix 3

Other Types of Tests

Step drawdown tests (Appendix 1) and constant rate discharge tests (Appendix 2) are the most common type of tests to carry out. However, other forms of test do exist, including:

- recovery tests (after the cessation of pumping);
- tests involving variable pumping rates;
- free-flow tests on artesian wells;
- slug tests (in small diameter piezometers in low permeability strata).

Test procedures and analysis methods for these less common type of tests are described in Krusemann and de Ridder (1994), as well as other tests.